Geostationary Operational Environmental Satellite (GOES)

GOES-R Series

Magnetometer

Performance and Operational Requirements Document (PORD)

Draft

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1 Scope

1.1 Identification

This Performance and Operational Requirements Document (PORD) sets forth the performance requirements for the National Oceanic and Atmospheric Administration (NOAA) Magnetometer Instrument.

1.2 Mission Review

The Magnetometer Instrument objectives are as follows:

- Measure the magnitude and direction of the Earth's ambient magnetic field in three orthogonal directions in an Earth-referenced coordinate system.
- Map the space environment that controls charged particle dynamics in the outer region of the magnetosphere.
- Determine general level of geomagnetic activity, monitors current systems in space.
- Detect magnetopause crossings, storm sudden commencements, and substorms.

1.3 Document Overview

This document contains all performance requirements for the Magnetometer Instrument and Ground Support Equipment (GSE).

1.4 Terminology

The term “TBD” means “to be determined”. This is applied to requirements or values that have not been defined. The contractor shall propose a requirement or value and provide a rationale for all TBD requirements. TBD requirement proposals shall be made in coordination with the government or other contractors. The contractor shall request approval from the government before proceeding with its proposed requirement or value.

The term “TBR” means “to be reviewed”. This is applied to requirements or values that are subject to review by the Government and the contractor. The contractor shall review and provide a value and rationale for all TBR requirements. The “TBR” provides an indication that the value may change upon review. TBR requirement proposals shall be made in coordination with the government or other contractors. The contractor shall request approval from the government before proceeding with its proposed requirement or value.

The term “(TBS)”means “to be supplied. The government will supply TBS requirements. The government will provide a date or milestone at which each TBS requirement will be supplied

1.5 Definitions

Throughout this document, the following definitions apply:

Accuracy: Refers to the error in a measurement that is the difference between the measured and true value. It includes both systematic and random errors. Systematic errors must be estimated from an analysis of the experimental conditions and techniques. Random errors can be determined, and reduced, through repeated measurements under identical conditions and a Standard Deviation calculated. The magnitude of a random error **shall** be taken as three standard deviations (3σ).

Data Latency: The time interval between the end of a data collection sequence and the time that the data is available at the Ground.

Earth Centric Inertial (ECI) coordinate system: The X-axis is in the equatorial and ecliptic planes in the direction of the first point of Aries (vernal equinox). The Z-axis is coincident with the Earth's rotational axis and is positive towards North. The Y-axis completes a right-handed orthogonal set, $\boldsymbol{Y} = \boldsymbol{Z} \times \boldsymbol{X}$ and lies in the equatorial plane. This coordinate system is also called Geocentric Celestial Inertial (GCI) or Geocentric Equatorial Inertial (GEI) coordinate system.

Eclipse: Defined as when the solar disk is completely or partially occulted by the Earth or Moon as viewed from the spacecraft.

Fully Functional Configuration: Being able to collect the full complement of science data; determine instrument response changes; acquisition of sensor health and status data; generation of sensor, calibration, monitoring, health and status data streams; and reception and execution of command and control data.

Geographic/Satellite Coordinate System: A coordinate system in which the Z axis is normal to the satellite orbital plane, positive northwards; the X axis is perpendicular to Z and directed toward Earth's center, and the Y axis completes an orthogonal set, $\boldsymbol{Y} = \boldsymbol{X} \times \boldsymbol{Z}$ and is positive eastwards.

Goal**:** A requirement that is desirable to achieve.

Launch: The period of time between lift off and the separation of the GOES-R series satellite from the launch vehicle.

Magnetometer Instrument: Consists of an electronics unit and one or more boom mounted tri-axial magnetic sensors.

Measurement Resolution: Resolution of the A/D converter.

Random errors: Unrepeatable statistical fluctuations in the measured data due to the precision limitations of the measurement.

Resolution: Ability to distinguish two adjacent features in the spectral, spatial or temporal domain.

Station Keeping: On-orbit spacecraft maneuver that corrects for orbital drifts.

Systematic errors: Consistently reproducible inaccuracies in the measured data due to the precision limitations of the measurement.

Threshold: A requirement which must be met.

Unit: A functional subdivision of a subsystem and generally a self-contained combination of items performing a function necessary for the subsystem's operation. Examples are electronics unit and sensor unit(s).

Yaw Flip: An on-orbit maneuver that rotates the spacecraft 180º about the spacecraft z axis (yaw). The net effect reverses the signs of the roll and pitch axes while maintaining yaw pointing at nadir.

1.6 Requirement Applicability

All requirements apply over the entire life of the Magnetometer Instrument. All requirements in this Magnetometer Instrument PORD apply to data after all ground processing except as indicated.

1.7 Requirement Weighting Factors

The requirements stated in this Magnetometer Instrument PORD are not of equal importance or weight. The following paragraphs define the weighting factors incorporated in this document.

The term "*shall*" designates a requirement. The term "*will*" designates a statement of fact.

2 Reserved

3 Magnetometer Instrument Requirements

The following requirements apply to the Magnetometer Instrument.

3.1 Magnetometer Instrument Definition

3.1.1 Overview and Description

The Magnetometer Instrument **shall** measure the magnitude and direction of the Earth's ambient magnetic field at geosynchronous orbit in three orthogonal directions in an Earth-referenced coordinate system.

Magnetometer Instrument measurements provide data to map the space environment that controls charged particle dynamics in the outer region of the magnetosphere and provide information on the general level of geomagnetic activity, monitor current systems in space, and permit detection of magnetopause crossings, storm sudden commencements, and substorms.

3.1.2 Instrument Modes

All Magnetometer Instrument Modes and their function **shall** be documented.

The Magnetometer Instrument **shall** complete all commanded mode transitions within 10 seconds (TBR).

The Magnetometer Instrument **shall** transition from its current mode to any other mode without causing damage to the instrument.

The Magnetometer Instrument **shall** provide command and housekeeping telemetry functions in all

powered modes.

3.1.2.1 Safe Mode

The Magnetometer Instrument **shall** implement a Safe Mode.

The Magnetometer Instrument **shall** be in a safe configuration for an indefinite period of time while in Safe Mode.

The Magnetometer Instrument **shall** enter the Safe Mode upon detection of internal faults that are capable of causing damage to the instrument.

Transitions to Safe Mode, whether commanded or autonomous, **shall** require no more than 1 second (TBR).

Transition from Safe Mode to Normal Operational Mode **shall** not exceed 10 minutes (TBR).

3.1.2.2 Normal Operational Mode

The Magnetometer Instrument **shall** implement a Normal Operational Mode. In Normal Operational Mode, the Magnetometer Instrument **shall** be in a fully functional configuration.

3.1.2.3 Instrument Diagnostic Mode

The Magnetometer Instrument **shall** implement a Diagnostic Mode(s) capable of operation on-orbit and during pre-launch ground testing.

In Instrument Diagnostic Mode the Magnetometer Instrument **shall** be in a fully functional configuration.

The Magnetometer Instrument Diagnostic Mode(s) **shall** be ground-commandable during on-orbit operation.

The Magnetometer Instrument Diagnostic Mode(s) **shall** be able to be terminated by ground command during on-orbit operation.

The Magnetometer Instrument Diagnostic Mode(s) **shall** auto terminate after the completion of the calibration cycle.

In Instrument Diagnostic Mode, the Magnetometer Instrument **shall** send data from all detectors with the value of a known field added to the ambient field such that the calibration field levels are at least 50% of the full range of the magnetometer sensors.

In Instrument Diagnostic Mode, the Magnetometer Instrument **shall** send all bits from the A/D converter.

In Instrument Diagnostic Mode, the Magnetometer Instrument **shall** perform electronic calibration (TBD).

In Instrument Diagnostic Mode, the Magnetometer Instrument **shall** be stable and repeatable during times of unchanging ambient field to an accuracy of ±1 nT in each axis at each field level.

3.1.2.4 Off Mode

The Magnetometer instrument **shall** be unpowered in the off mode.

The Magnetometer Instrument **shall** be capable of being in the off mode during on-orbit storage.

The Magnetometer Instrument **shall** be capable of being in the off mode for an indefinite period of time.

3.1.3 On-Orbit Operations

If the Magnetometer instrument is powered down to conserve spacecraft power it **shall** be capable of returning to Normal Operational Mode within 10 minutes (TBR) after power is applied.

3.1.3.1 Initial Activation

The Magnetometer instrument **shall** be capable of operating prior to and during magnetometer boom deployment, meeting all requirements except those related to orientation and spacecraft magnetic fields.

3.1.3.2 Eclipse

The Magnetometer instrument **shall** be capable of meeting all requirements through eclipse periods.

3.1.3.3 On-Orbit Storage

The Magnetometer instrument **shall** be capable of being in the Normal Operational Mode or in the off mode during on-orbit storage.

The Magnetometer instrument **shall** meet all requirements within 10 Minutes (TBR) after on-orbit post storage activation.

3.1.3.4 Operation During Spacecraft Maneuvers

3.1.3.4.1 Yaw Flip

The Magnetometer instrument **shall** be capable of operating during a yaw flip maneuver, meeting all requirements except those related to orientation.

The Magnetometer instrument **shall** meet all requirements within 10 minutes (TBR) after a yaw flip.

3.1.3.4.2 Station Keeping

The Magnetometer instrument **shall** be capable of operating during spacecraft station keeping maneuvers, meeting all requirements except those related to orientation.

The Magnetometer instrument **shall** meet all requirements within 10 minutes (TBR) after spacecraft station keeping maneuvers.

3.1.3.5 Reliability

The Magnetometer instrument **shall** have Reliability (R) of at least 0.6 after 10 years of on-orbit operations, preceded by up to 5 years of ground storage and up to 5 years of on-orbit storage.
The Magnetometer instrument **shall** have a Mean Mission Duration (MMD) of 8.4 years for a design life of 10 years.

3.2 Sensor Requirements

3.2.1 Measurement Range

The Magnetometer instrument **shall** have an ambient field measurement range of at least ± 400 nT in each of the three orthogonal axes.

3.2.2 Orthogonality Requirement

The three sensors of the tri-axial Magnetometer instrument **shall** be orthogonal to within +/ - 0.5 Degrees.

3.2.3 Accuracy Requirement

The Magnetometer instrument **shall** measure the magnetic field to an accuracy of 1.0 nT per axis.

3.2.4 Resolution Requirement

The Magnetometer instrument **shall** measure the magnetic field with a resolution of at least 0.016 nT per axis.

3.2.5 Temporal Resolution

3.2.5.1 Sampling Rate

Each of the three orthogonal ambient magnetic field components **shall** be sampled at a rate of 2 Hz ± 20% (Threshold, Goal: 8 Hz ± 20%).

Each of the three orthogonal ambient magnetic field components **shall** be sampled uniformly in time.

The magnetometer instrument **shall** provide the effective time of each measurement.

3.2.5.2 Synchronicity of Compone nt Sampling

Each of the three orthogonal ambient magnetic field components **shall** be sampled simultaneously within 25% of the sample period.

3.2.5.3 Passband

The measurement bandwidth for each component of the vector field **shall** be defined by a pre-sampling anti-aliasing filter with frequency cut-off characteristic equivalent to or better than a fifth order Butterworth filter.

The anti-aliasing filter nominal 3 dB attenuation frequency **shall** be one-fourth the sampling frequency.

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The frequency at one-half the sampling frequency is known as the Nyquist folding frequency

The three components of the anti-aliasing filter **shall** be matched to the nominal 3 dB frequency ± 0.75%.

The anti-aliasing filter **shall** have a 25 dB attenuation at one half the data sampling frequency.

The actual frequency response of the magnetic field measurement **shall** not deviate from the nominal by

more than 0.3 dB in amplitude or 5° in phase anywhere within the nominal 3 dB bandwidth.

3.2.5.4 Status Data

The Magnetometer Instrument **shall** include status data to indicate mode of operation at the same rate as the science data.

4 Spacecraft Requirements

4.1 Spacecraft Magnetic Requirements

The spacecraft **shall** provide for normal operations all telemetry necessary to calculate the magnetic field in spacecraft Body Reference Frame (BRF) coordinates, Geographic/Satellite Coordinates, and Earth Centric Inertial (ECI) coordinates with a latency of less than 5.0 seconds.

The Spacecraft **shall** provide telemetry to correct, with a latency of less than 5.0 seconds, for spacecraft generated magnetic fields that exceed ambient magnetic field accuracy requirements

The estimate of the magnitude of the ambient field computed on the ground from the instrument measurement along each axis **shall** not fluctuate by more than 0.3 nT, when the spacecraft is in a normal operational mode.

Unavoidable step changes, which create out-of-specification transients after ground correction, **shall** not average more than one transient in any one-hour period.

The duration of the out-of-specification transients **shall** be no greater than five seconds.

The spacecraft **shall** provide magnetometer instrument orientation stability of ± 0.25 Degrees (TBR)

The spacecraft **shall** provide magnetometer instrument orientation knowledge of ± 1.0 Degrees; (Goal ± 0.5 Degrees)

The spacecraft **shall** be designed to have no permeable or permanent magnetic material within 3 meters of the magnetometer instrument sensor.

The spacecraft **shall** be designed to have a static magnetic field of less than 100 nT at the magnetometer instrument sensor.

The latency of a Magnetometer Instrument three-axis sample data set from the time of the last data collection to receipt of the data on the ground **shall** be no more than 2.0 seconds (TBR).

4.2 Spacecraft Magnetic testing

The Magnetometer instrument zero offset **shall** be measured at a minimum, before and after integration on the spacecraft, and after environmental testing.

A ground based stray magnetic field measurement **shall** be made to verify that the spacecraft magnetic field requirement at the magnetometer instrument sensor(s) is met in normal mode and spacecraft on-orbit storage mode.

A ground based spacecraft magnetic dipole moment measurement **shall** be made to verify that the spacecraft static magnetic field requirement at the magnetometer instrument sensor(s) has been met.

The effective magnetometer instrument zero offset (instrument plus spacecraft) **shall** be determined on-orbit via a spacecraft rotation maneuver.

The Magnetometer instrument on-orbit zero offset measurement **shall** be made during the spacecraft post-launch test period in the vicinity of local noon.

4.3 Status Data

The Spacecraft **shall** provide a three state status, at a rate of at least once every 5.0 seconds to indicate the orientation of the spacecraft as one of the following conditions:

Within 5 degrees of Normal Orientation

Within 5 degrees of Yaw Orientation

Greater than 5 degrees off Normal or Yaw Orientation
When the magnetometer instrument is in the off mode, the spacecraft shall provide fill values for the magnetometer instrument data that is distinguishable from the magnetometer instrument data in the Normal Operational Mode.

4.4 Algorithms

The Spacecraft contractor **shall** provide for normal operations, the algorithms necessary to calculate the magnetic field in spacecraft BRF, Geographic/Satellite, and Earth Centered Inertial coordinates with a latency of less than 5.0 seconds.

The Spacecraft contractor **shall** provide algorithms to correct, with a latency of less than 5.0 seconds, for spacecraft generated magnetic fields that exceed ambient magnetic field accuracy requirements.

4.5 Magnetometer Turn-On

The Spacecraft **shall** be capable of supporting the turn-on of the Magnetometer Instrument at least one hour prior to the deployment of the magnetometer boom.

5 Acronyms

A/D	Analog to Digital
BRF	Spacecraft Body Reference Frame as defined in the GOES-R General Interface Requirements Document
cm	centimeter
ESTE	Electrical System Test Equipment
GIRD	General Interface Requirements Document
GOES	Geostationary Operational Environmental Satellite
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
Hz	Hertz

ICD	Interface Control Document
K	Kelvin
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
nT	Nano Tesla
PORD	Performance and Operational Requirements Document
R	Reliability
TBD	To Be Determined
TBR	To Be Reviewed
TBS	To Be Specified